CURTISS DIVISION
CURTISS-WRIGHT CORPORATION
CALDWELL, NEW JERSEY

Curtiss-Wright

Mechanical Control and Actuation Systems

... a solution
to powered control and actuation problems for designers and builders of land, sea, and aerospace vehicles

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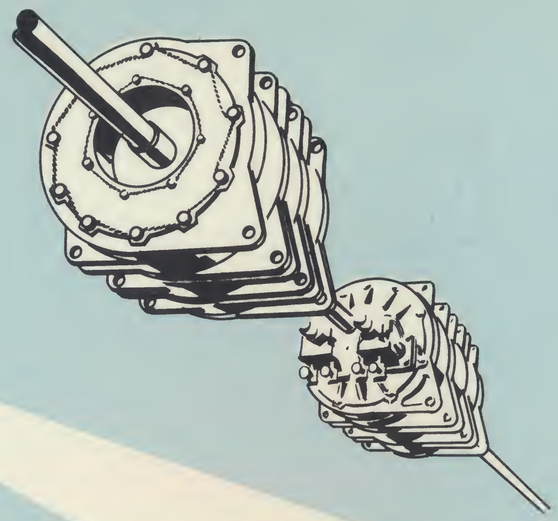
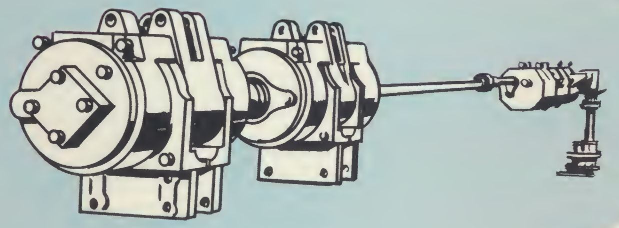
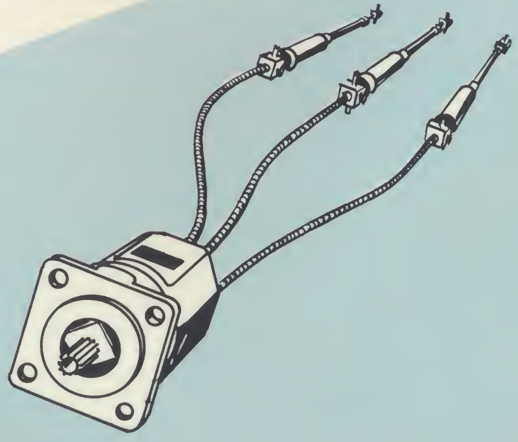
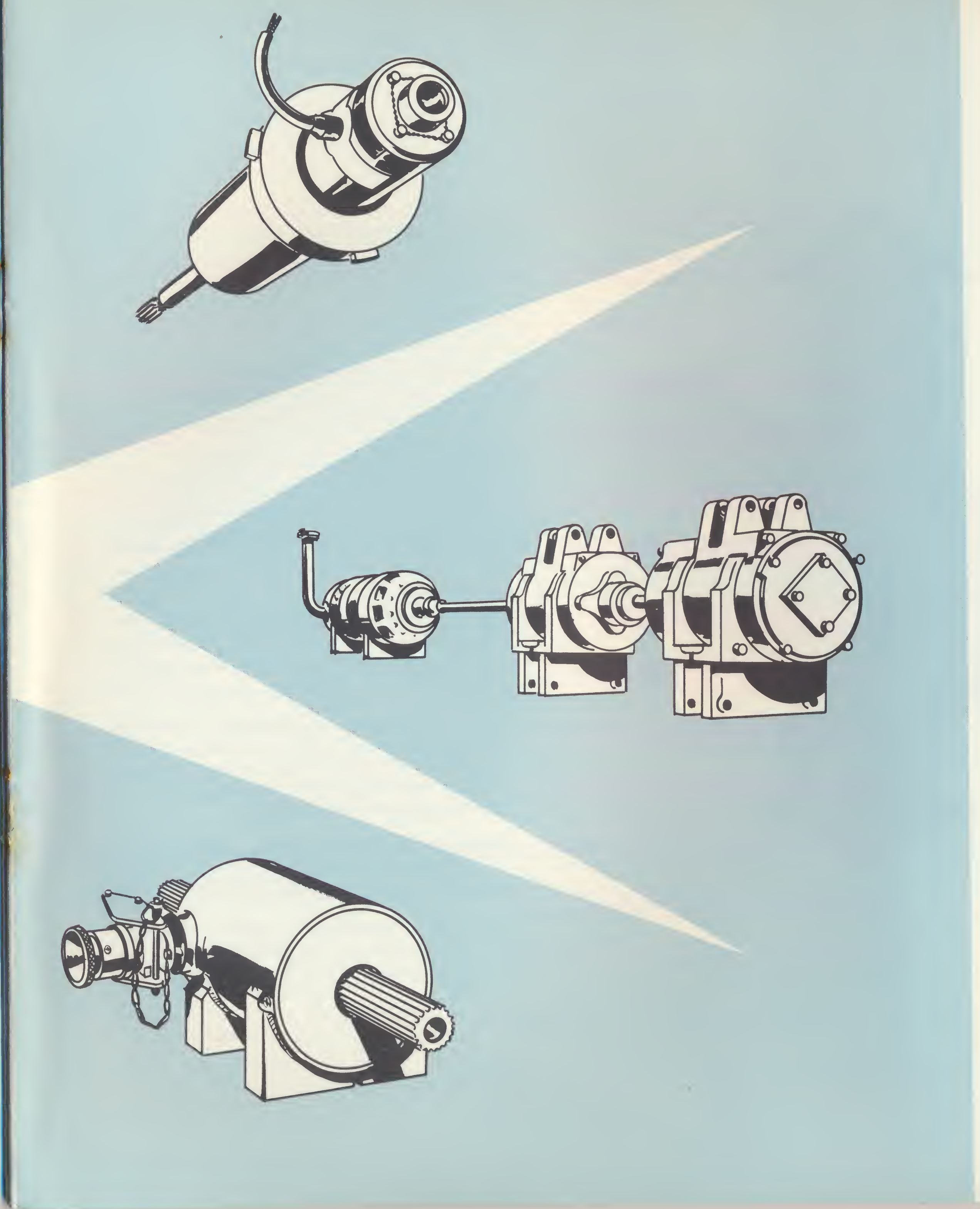








FOREWORD

The rapid development of advanced aircraft, missiles and spacecraft has posed severe design problems for powered control and actuation systems involving thermal environment, dynamic response, and efficient use of power. Conventional systems, using ingenious extensions of previously used principles, have had varying degrees of success, usually at the expense of simplicity and reliability.

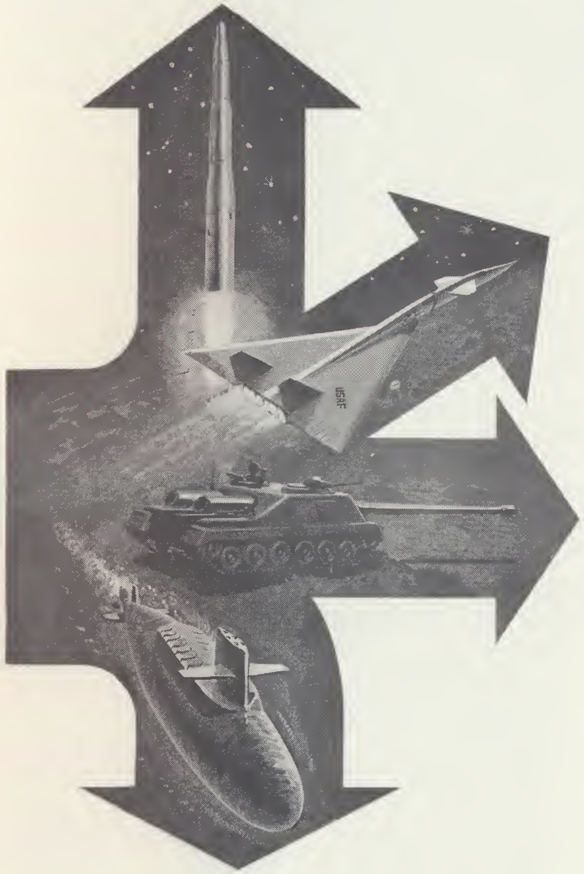
After careful evaluation of electrical, hydraulic and mechanical systems, gained through more than 20 years experience in their design and fabrication, the Curtiss Division has found the mechanical system to have the greatest development potential. This is proving to be a most efficient and reliable solution to the control problems encountered in many land, sea and aerospace applications.

In selecting, developing, and testing this newest concept in powered control systems, it has been found that it out-performs others and provides extra benefits as well. Inherent characteristics assure fulfillment of present-day requirements and readily adapt to foreseeable future demands—not only as applied to advanced vehicles, but extended to many devices to be powered and positioned.

On the following pages, the Curtiss-Wright mechanical control systems and basic components are described. The information covers how the systems work, where they are used and why, and the benefits derived.

MECHANICAL CONTROL AND ACTUATION SYSTEM

ADVANTAGES



The mechanical control system makes each of the following advantages readily available for application to land, sea, and aerospace vehicles.

1. It is the simplest system. No power conversion is required from the source of rotary power to the actuated part.

2. It is the lightest system. Carrying loads in mechanical components is most efficient from a weight standpoint. Compactness also allows significant savings in vehicle structural weight and volume. This results in savings of up to one-half the installed weight of conventional systems.

3. It is the most efficient system. High mechanical efficiency, combined with power-matching and power-limiting features, assures lowest power consumption.

4. It is the least cost system for extreme environments. The mechanical system benefits from current funded material research, cooling provisions, weight reduction, and simpler, lower cost vehicle structure.

5. It is the best future growth system. Its potential increases with progress of metallurgy and lubrication technology.

6. It is a dependable system. Mechanical components have a good history of predictable reliability.

INTRODUCTION TO MECHANICAL CONTROL AND ACTUATION SYSTEMS

Curtiss-Wright mechanical control systems are position control devices constructed essentially of mechanical components. They extract unidirectional mechanical power from a rotary power source such as found in the engines of aircraft and powered vehicles, and transmit this power to produce control movement without conversion to other forms of energy.

Figure 1 illustrates two typical types of powered actuation systems: continuous and intermittent. Continuous actuation is represented by a system such as the flight control system of an air vehicle. Landing gear retraction represents the intermittent type of actuation system. Rotary input power is supplied to the two systems by either mechanical, pneumatic, or hydraulic sources.

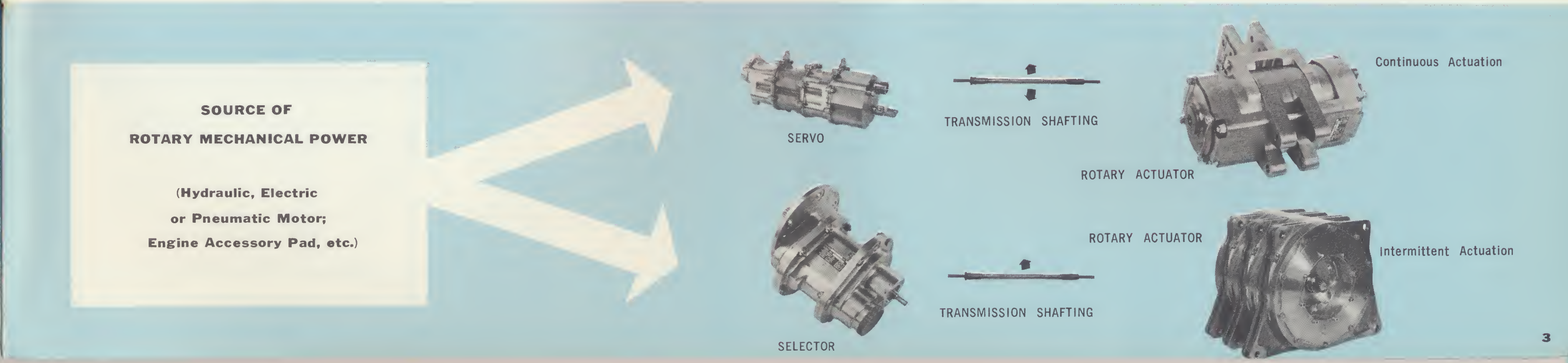
Four basic components are involved in the mechanical actuation system. These are the actuators, spring-clutch servos, selectors, and transmission shafting.

A spring-clutch servo is used as the control unit for the continuously-modulating actuation system. It controls the flow of power, in both rate and direction, in response to input signals. Operational features of the servo are rapid response, and efficiency on the order of 95%.

The selector unit is used as the control element for the intermittent actuation systems. It is generally a constant-rate control which takes advantage of the indexed character of mechanical systems to provide the features of integral holding, sequencing, and signaling functions.

Lightweight shafting may be used to transmit the power from the control units to remotely-mounted actuators which move the load. When the Power-Hinge type actuator is used, it performs the dual function of hinge *and* actuator. It offers a minimum installed weight for a given capacity, and provides a very stiff coupling between the fixed structure and the device to be actuated.

Figure 1. TYPICAL POWERED ACTUATION SYSTEMS



COMPARISONS WITH OTHER SYSTEMS

A Curtiss-Wright mechanical aileron control system for an advanced fighter aircraft was laboratory tested and evaluated in a joint development program with a prominent aerospace-craft manufacturer. During this evaluation, several important capability comparisons were made with other systems. It was determined that the mechanical system offered important advantages in areas of weight-versus-temperature, dynamic response, power efficiency, and radiation tolerance.

Weight Versus Temperature

As shown in Figure 2, the mechanical system offers a relative weight saving over other systems designed to fulfill the same requirements of power output, comparable life, and reliability. This comparison is based on current weight analysis data used in analyzing advanced projects. Part of the advantage offered by the mechanical system is based on obtaining the required reliability with less redundancy than the usual fluid system.

Dynamic Response

In response to command signal inputs, the mechanical system, with its on-off response characteristics, has less lag time than the proportional types, as shown in Figure 3. The hot gas and pneumatic systems have additional lags due to the compressibility of the fluids used. Lag in the electrical system is due primarily to its low torque-to-inertia ratio. Response of the electrical system can be improved by using continuously-running motors and clutches. This is effective for low power applications, but induces severe weight penalties as the power level is increased.

Power Efficiency

Inefficiency of a control system results in wasted energy which produces heat and may require additional cooling equipment which, in turn, adds weight.

All systems are sized by the maximum load to be actuated, response rate, and stiffness requirements. Because normal loads are usually a small fraction of maximum design load, a continuous pressure drop across the servo valves of a hydraulic system results in a lowering of efficiency.

Hot gas and pneumatic systems are similar to the hydraulic systems with one exception. When using a non-expanding cycle, half the available energy is wasted when a cylinder is actuated.

Electrical system inefficiency is the result of power conversion losses.

The mechanical system does not contain any of these energy losses; therefore, it can operate at higher power efficiency.

Radiation Tolerance

Systems constructed entirely of metal, such as mechanical and pneumatic, are less susceptible to radiation damage as compared to those utilizing fluids for power transmission, or magnetic properties for energy conversion. Radiation effects on fuels used in hot gas systems may also result in less efficient energy extraction.

Figure 2. WEIGHT VS. TEMPERATURE

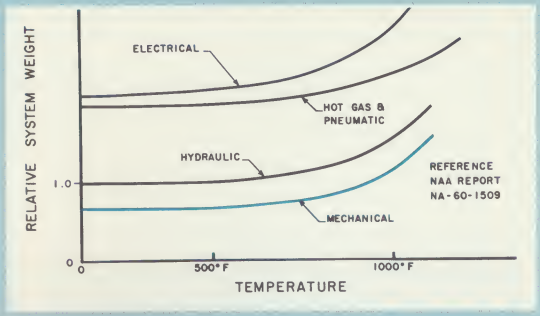
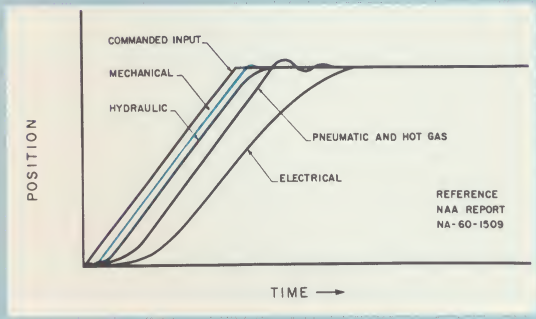
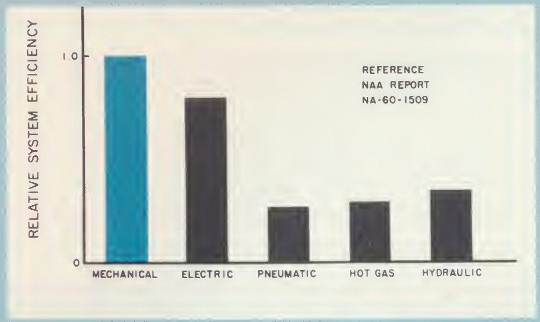


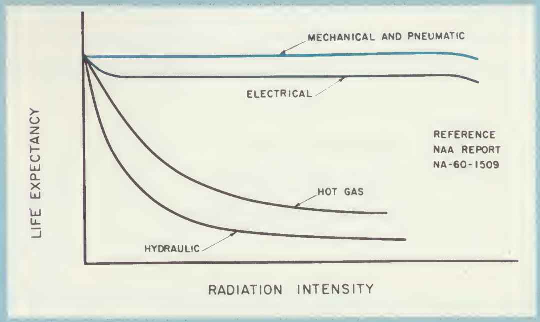
Figure 3. DYNAMIC RESPONSE



POWER EFFICIENCY



RADIATION TOLERANCE



CONSTANT POWER CONCEPT

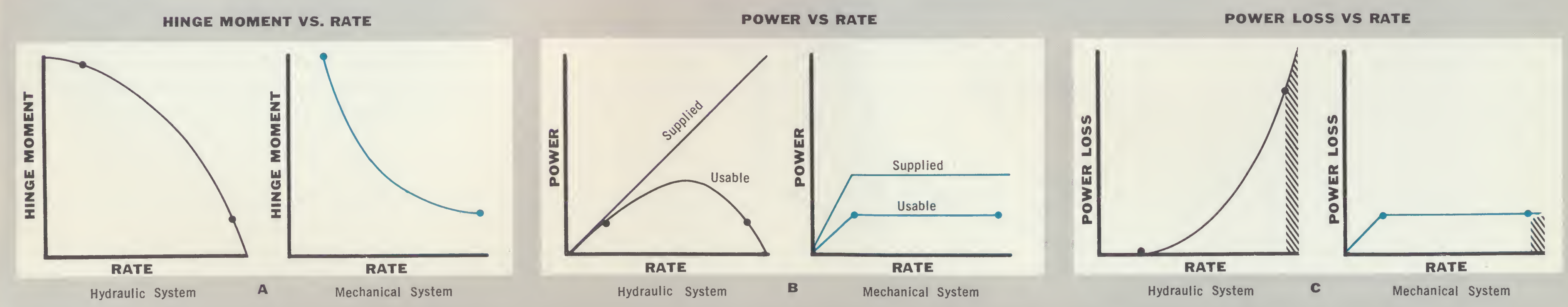
A significant feature of the mechanical control and actuation system is its capability to provide a specific relationship between system load and system rate. One interesting relationship which can be provided is that of constant peak power throughout the rate range of the system. This is compatible, for example, with the actuation requirements of flight control surfaces. Here low rates are required at high loads, and high rates at low loads to achieve maximum maneuvering capability for the vehicle.

Normally, system design is based upon maximum maneuvering requirements for at least two flight conditions. Refer to Figure 4A which compares the maximum hinge moment and rate capability of the mechanical system with that of a conventional fluid system. The two points shown on the curve might represent high speed at high load conditions, and landing at low load conditions. The flow-pressure type system delivers greater power than required at the off-design conditions between the specified two points. This means that either the structure must be made stronger and heavier to absorb the power, or some device must be incorporated to limit the power to that required at the design points. A limiting device of this type usually provides a by-pass feature which dissipates power. This results in lowering of overall system efficiency, and an increase in weight to handle the additional cooling requirements.

As shown in Figure 4B the fluid system supplies power in proportion to system rate. At slow rates the system efficiency is high, but drops rapidly as rate is increased. The usable power diverges accordingly, inducing high power-losses as illustrated.

By comparison, the mechanical system operates at constant efficiency—independent of system rate. It supplies power at a level which is a constant increment higher than the usable peak power required. The system power loss is also constant, and at the high rate conditions is very low compared to that of the fluid system. In typical flight control applications, well over 90% of normal system operation occurs in the regions of small surface deflections, low loads, and high rates as designated by the shaded areas of Figure 4C Obviously, significant savings in overall mission power drain can be realized by utilizing the mechanical system.

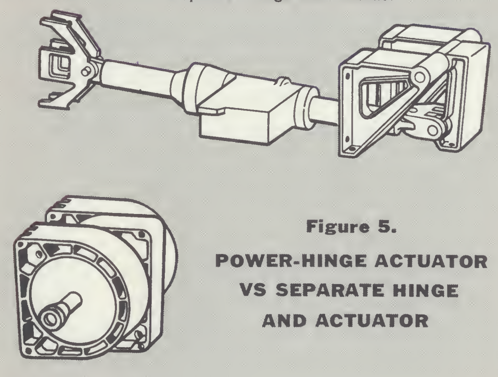
Figure 4.



DESCRIPTION OF COMPONENTS

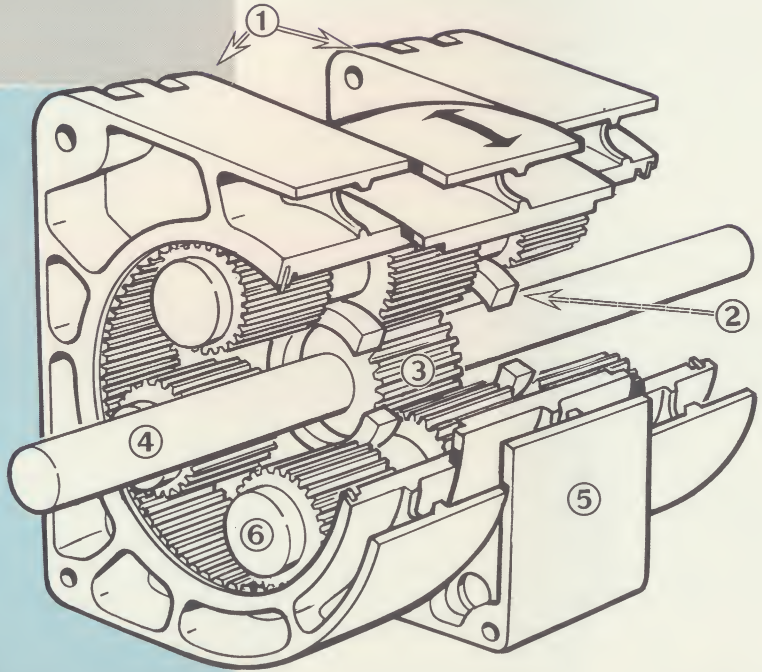
Design Concepts -- Operating Principles -- Benefits

Separate Hinge and Actuator



Power-Hinge Actuator

Figure 5.
POWER-HINGE ACTUATOR VS SEPARATE HINGE AND ACTUATOR



1 **Fixed Rings**

2 **Support Ring**

3 **Sun Gear**

4 **Input Shaft**

5 **Output Ring**

6 **Spindle**

Figure 6.
SCHEMATIC OF POWER-HINGE ACTUATOR

POWER-HINGE AND OTHER SPINDLE TYPE ROTARY

. . . new compact, balanced-spindle devices with high stiffness characteristics.

Mechanical system components are capable of delivering power by means of either rotary or linear motion. Rotary motion, however, is required in a majority of applications. For this reason, the following discussion is concerned only with the series of unique rotary actuators which have evolved during the mechanical system development.

Curtiss-Wright rotary actuator designs are based upon a balanced-spindle, multiple-gear planetary arrangement. An especially useful configuration of this arrangement is the Power-Hinge actuator.

Power-Hinge

Greatest simplicity and space savings is realized when the driving shafts of actuators are located on the hinge-line of the element which is to be positioned. This type of rotary actuator has been developed by the Curtiss Division and named the Power-Hinge.

ACTUATORS

The Power-Hinge is a new concept in mechanical rotary actuators. It permits both actuator and hinge to be combined into a single, compact unit. The structural and space (volume) advantages of this configuration are illustrated in figure 5, which compares the Power-Hinge actuator with a typical fluid system actuator.

Essentially, the Power-Hinge is a high ratio, compound, epicyclic speed reducer. (See Figure 6). The load, mounted on the Power-Hinge output ring, is distributed over many gear teeth through use of a large number of "spindles" acting as planets. These spindles each have three rows of teeth with forces on the outer rows being balanced by the force on the center row.

Conventional planetary gearing requires a planet carrier and a shaft in each planet. The balanced forces on the Power-Hinge spindles avoid the need for such a planet carrier. The spindles in the Power-Hinge are free to adjust their position which insures an even distribution of load. This results in greatly increased load capacity for a given size unit.

For extremely high reduction ratios, two stages are compounded to give slower motion of the controlled surfaces at very high torque levels. A dramatic application of the torque handling capability of this type Power-Hinge, used on the B-70 airplane, is described on page 15.

Power-Hinge actuators, depending upon the specific application, exhibit a torque carrying capacity ranging from 3,500 to 20,000 inch-pounds per pound of actuator. Actuated loads are, in effect, keyed or splined to the stationary structure by multiple spindles which engage both the movable and stationary gears. This arrangement, tests show, enables the Power-Hinge to be many times stiffer than equivalent linear actuators or other present systems. High stiffness reduces output problems such as flutter, and provides better control of the element to be moved.

For advanced applications, the Power-Hinge — acting as its own bearing, and operating without fluid lubricants or seals — eliminates the two major obstacles to reliable operation under extreme environmental conditions.

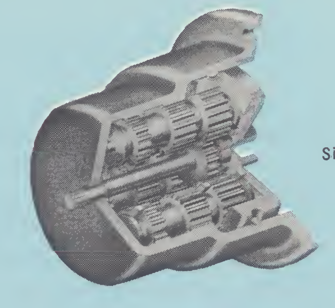
Other configurations

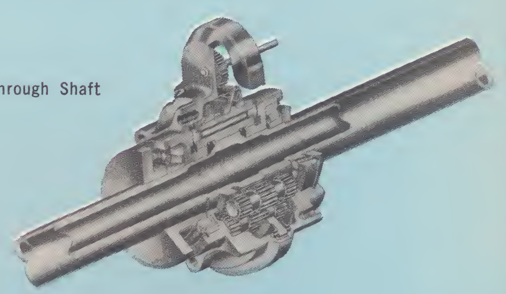
A variety of mechanical rotary actuators have been developed by the Curtiss Division in addition to the Power-Hinge configuration just described. See Figure 7.

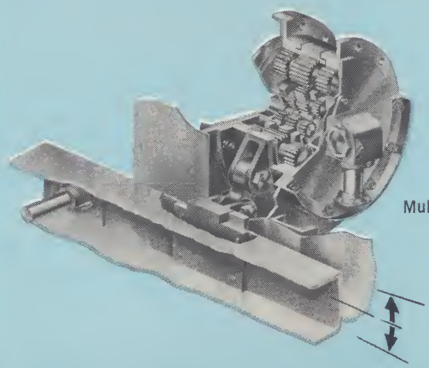
Unlimited-rotation actuators, utilizing the same balanced-spindle principle as the Power-Hinge, are available in single-shear and through-shaft configurations.

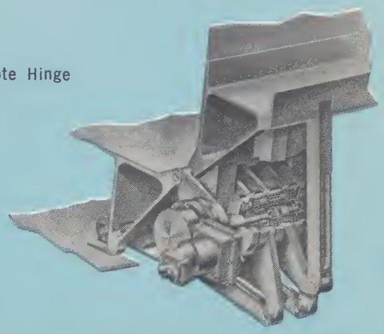
Remote-hinge and multiple-output are two additional variations of the balanced-spindle type actuator.

Figure 7. MECHANICAL ROTARY ACTUATORS


Single Shear


Through Shaft


Multiple Output


Remote Hinge

MECHANICAL SHAFTING

. . . an efficient, lightweight method for transmitting rotary power.

Mechanical shafting is used to efficiently transmit rotary power from the control unit to the actuators. The size and type of shafting is selected for each particular control application in order to provide minimum weight with optimum stiffness and inertia characteristics.

Mechanical shafting generally consists of short lengths of torque tubes coupled to each other by either flexible joints or crowned splines, and covered with lightweight non-rotating tubes. This jointed design permits a small amount of angularity for routing of the shafting through the vehicle and elastic deflections of the supporting structure.

Flexible couplings, formed of helically wound wire, are a new development in mechanical transmission shafting. These couplings can accept a large degree of misalignment, ±7 degrees, as compared to ±1½ degrees for spline types, and have been successfully tested in both unidirectional and reversing applications through millions of cycles, at ambient temperatures up to 1000°F. Quick-disconnect fittings are readily introduced into these shafts to facilitate maintenance, inspection and assembly.

Crown spline couplings in shafting systems are not new to the mechanical art, appearing in a large number of power transmission applications. They are somewhat lighter than flexible coupling types, although more restricted in their misalignment capacity. Spline couplings would normally be used for main power interconnections where misalignment requirements are less stringent.

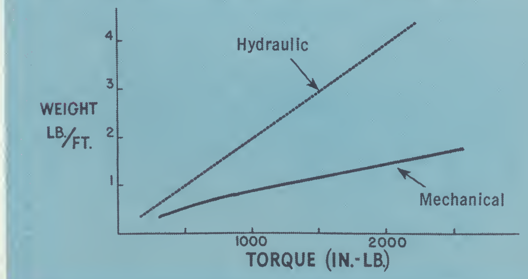
The use of mechanical shafting is an efficient, lightweight method of power transmission. As an example, refer to Figure 8. Here a 3000 rpm, 30 hp mechanical transmission system will weigh only ½ as much as a conventional hydraulic system of the same capacity. This comparison considers that the hydraulic transmission line consists of a supply line and a return line, each with fluid, and with an additional column of fluid for reservoir capacity. Supply pressure is 4000 psi with 3000 psi working pressure.

As can readily be seen, the divergence of the two systems is substantial as power increases. This divergence becomes even more pronounced as the operating shaft speed is increased.

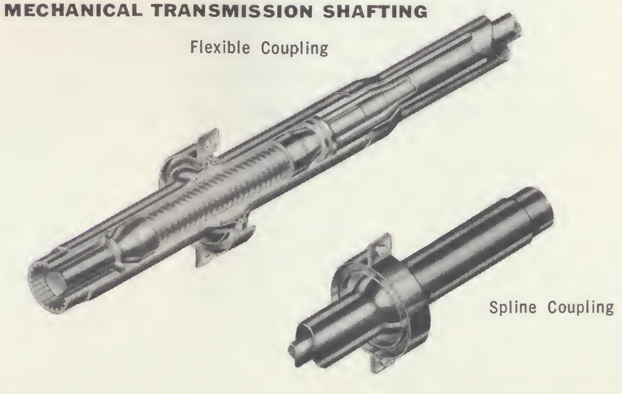
Alternate System

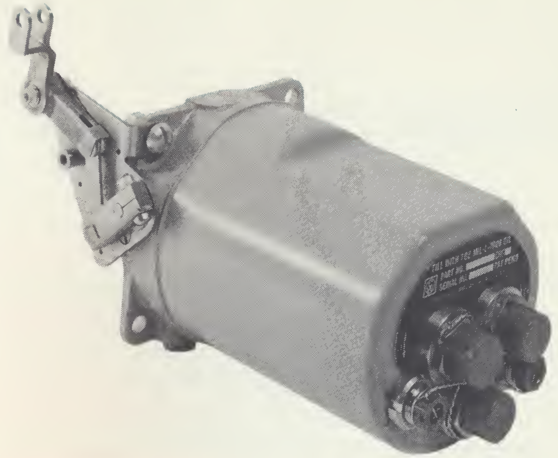
For very large advanced vehicles, such as supersonic transports or aerospace craft, a pneumatic power transmission system is an alternate to mechanical shafting. This would supplant long runs of shafting with tubes carrying ram or engine-bleed air to a small turbine at the load. A mechanical servo and actuator would control flow of power from the turbine to the load.

Figure 8. WEIGHT COMPARISON OF MECHANICAL AND HYDRAULIC TRANSMISSION



MECHANICAL TRANSMISSION SHAFTING



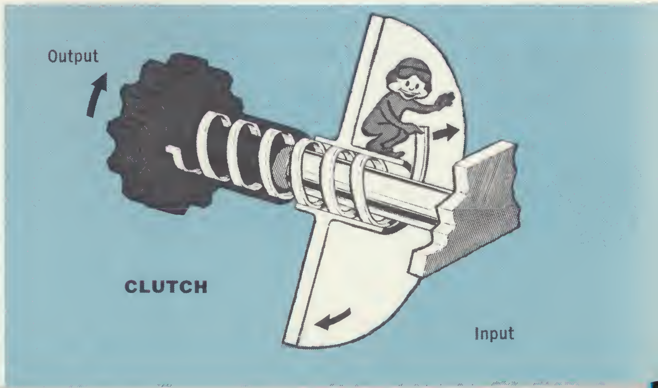


THE MECHANICAL SPRING-CLUTCH SERVO

. . . a lightweight, compact device for controlling continuous power flow.

The mechanical control system receives continuously rotating input power and produces bi-directional output in response to a signal. The system will also stop and hold the output when necessary. Moreover, it performs this function up to 15 or 30 times per second in response to low signal levels.

This task is accomplished by the mechanical servo which incorporates, as the heart of its make-up, the familiar spring-clutch . . . a device whose reliability has been established in many industrial



applications such as motors, computers, machine tools, power winches.

Basically, the spring-clutch servo performs three functions: that of a brake, a clutch, and a mechanical amplifier. Figure 9 illustrates how the servo performs these functions. Two spring-clutches (one for each direction) connect the continuously-running input to the output when power is to be transmitted to the load.

Clutch and brake functions of the spring-clutch are similar in nature and can be combined in one spring by utilizing both the inside and outside diameters. The helically wound spring acts as a mechanical amplifier, like a positive-engagement capstan, so that a low energy level signal will energize it.

Note here that spring-clutches are by nature on-off devices. They can be arranged to provide tri-stable control — that is: (1) full rate clockwise; (2) stopped, and (3) full rate counterclockwise.

The mechanical servo contains two spring-clutch assemblies mounted (in a typical configuration) side-by-side as shown in the schematic diagram, Figure 10. The clutches are operated by a mechanical linkage connected to an input signal lever.

The input shaft and rotors turn continuously. In the absence of an error signal, the servo output is locked (braked) by the interference fit between the clutch springs and stationary shafts. When an error signal is introduced, one of the clutch discs, depending on the direction of the error, moves axially and contacts the rotor.

The rotor then drives the disk, which in turn unwraps the teaser spring, expanding it away from the stationary shaft and up against the rotor. The teaser spring then rotates and expands the main spring in a similar manner. The main spring, in turn, drives the output until the error signal is removed. Simultaneous engagement of left and right-hand clutches is prevented by the geared interlock arrangement shown.

It is possible to introduce signals into the servo electrically by incorporating an electromechanical transducer into the system. The basic arrangement of clutches can be made to suit the particular application (side-by-side or in-line).

Operating Characteristics

The operating characteristics of spring-clutch servos are non-linear, as shown in Figure 11.

In response to an input signal, the mechanical servo follows a rapid on-off stepping function. When an error exists between the input signal and load positions, the servo operates at maximum rate in the required direction until the error is removed. Then the servo shuts off and holds the output in a braked position until an error is again recognized.

The mechanical servo's dynamic characteristics permit a lower maximum output rate than usual fluid systems require for equivalent vehicle response. This lower rate, made possible with the mechanical system, results in the added advantages of smaller, lighter hardware, reduction of dynamic loads on the reaction structure, and reduction of power drain. Moreover, since the servo draws no power when the error signal is zero, efficiency of the mechanism is high, and wear is held to a minimum.

Figure 11. SPRING-CLUTCH SERVO OPERATING CHARACTERISTICS

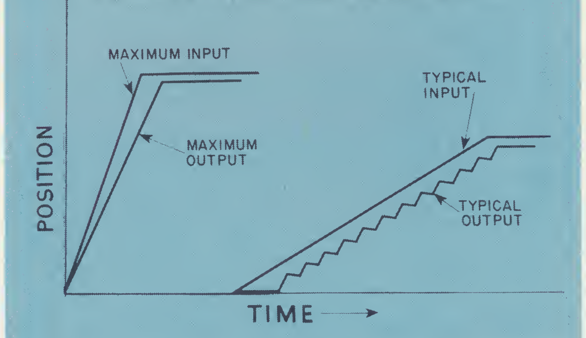


Figure 9. SPRING CLUTCH SERVO PRINCIPLES

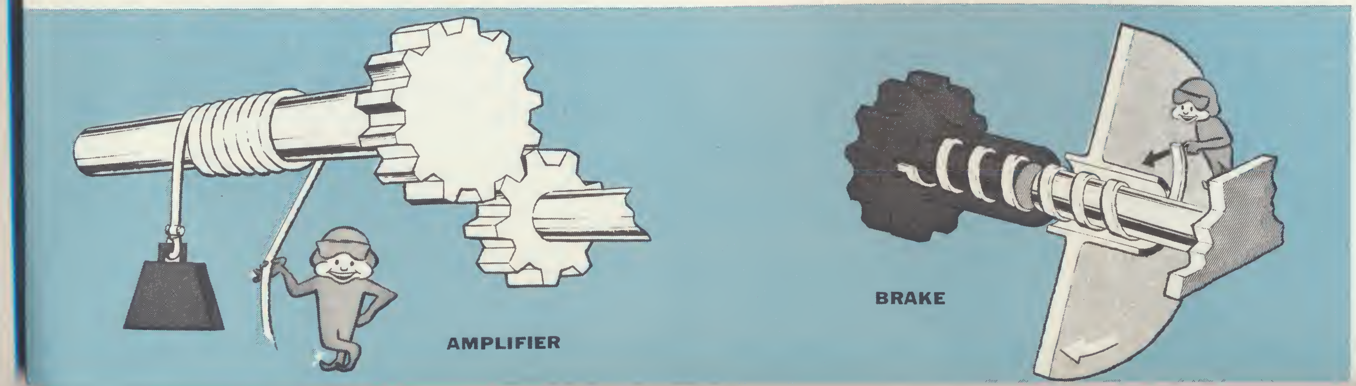
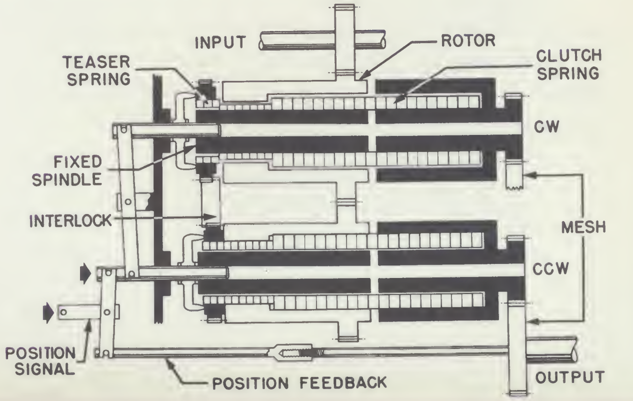
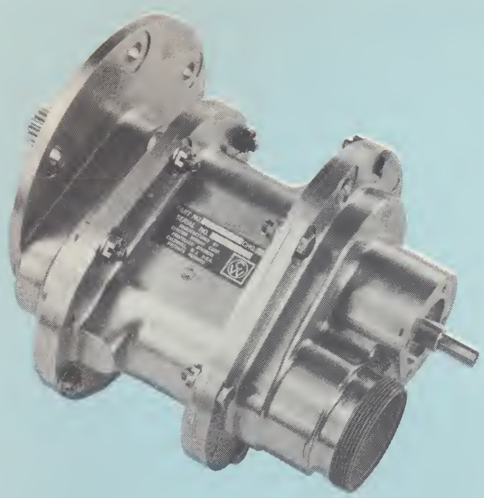


Figure 10. MECHANICALLY-ENERGIZED SPRING CLUTCH SERVO





SELECTORS

. . . clutch devices for controlling intermittent power flow.

The mechanical selector is an open-loop, on-off control unit. It is used as the control element for intermittent type actuation systems such as landing gear retraction, door operation, etc., where modulated closed-loop control is not required. Clutching elements of the disc type are usually employed. Output rate is dependent upon the speed of the input-drive power source.

Mechanical selectors take full advantage of the indexed nature of mechanical systems. Various functions such as holding and locking, sequencing, and limit stops can be integrated into the selector mechanism. This arrangement provides an exceptionally clean system installation.

INTEGRATED POWER AND ACTUATION SYSTEM

. . . a unique secondary power control and actuation system for advanced vehicles.

As previously mentioned in this brochure, the mechanical control and actuation system receives rotary power from sources such as turbines, electric, hydraulic or pneumatic motors; or directly from the vehicle's main power plant.

However, a new and unique Integrated Secondary Power Control and Actuation System has been developed by Curtiss-Wright which deserves mention here. This system — consisting of actuators, servo and interconnecting shafting . . . is powered by an integral rotary power source and can be conveniently located in the area where the actuation function is performed. The only connection required with the main vehicle is the input signal control line. Transmission of rotary power from the vehicle's main power plant is unnecessary.

The system is shown schematically in Figure 12. An integrated gas generator operates a turbine — which also functions as an inertia wheel — to make unidirectional rotary power available to the spring-clutch servo. The servo modulates this power in response to signal-input commands to provide the required motion of the actuators.

Such an arrangement offers distinct advantages to advanced air, space and re-entry vehicles in which the main power plant may be extremely remote to the actuation system, or, in the case of space and re-entry vehicles, the main power plant may not be in operation.

Several fundamental characteristics inherent to the mechanical control and actuation system has made this development possible and practical. The mechanical system (1) is capable of substantially reducing the power needed to do a specific job, (2) works most efficiently when closely coupled, (3) provides a constant power level throughout the required operating range, (4) is the only system which can economically store kinetic energy by means of an inertia wheel, and (5) has a lower secondary power drain than conventional fluid systems.

Power for various vehicle systems is stored in the chemical energy of the fuel. Investigation of the various methods of energy conversion and power transmission shows that the most effective and lightest system is of the hot gas type. Only one energy conversion is necessary, i.e. from the chemical energy of the fuel to the kinetic energy of the inertia wheel.

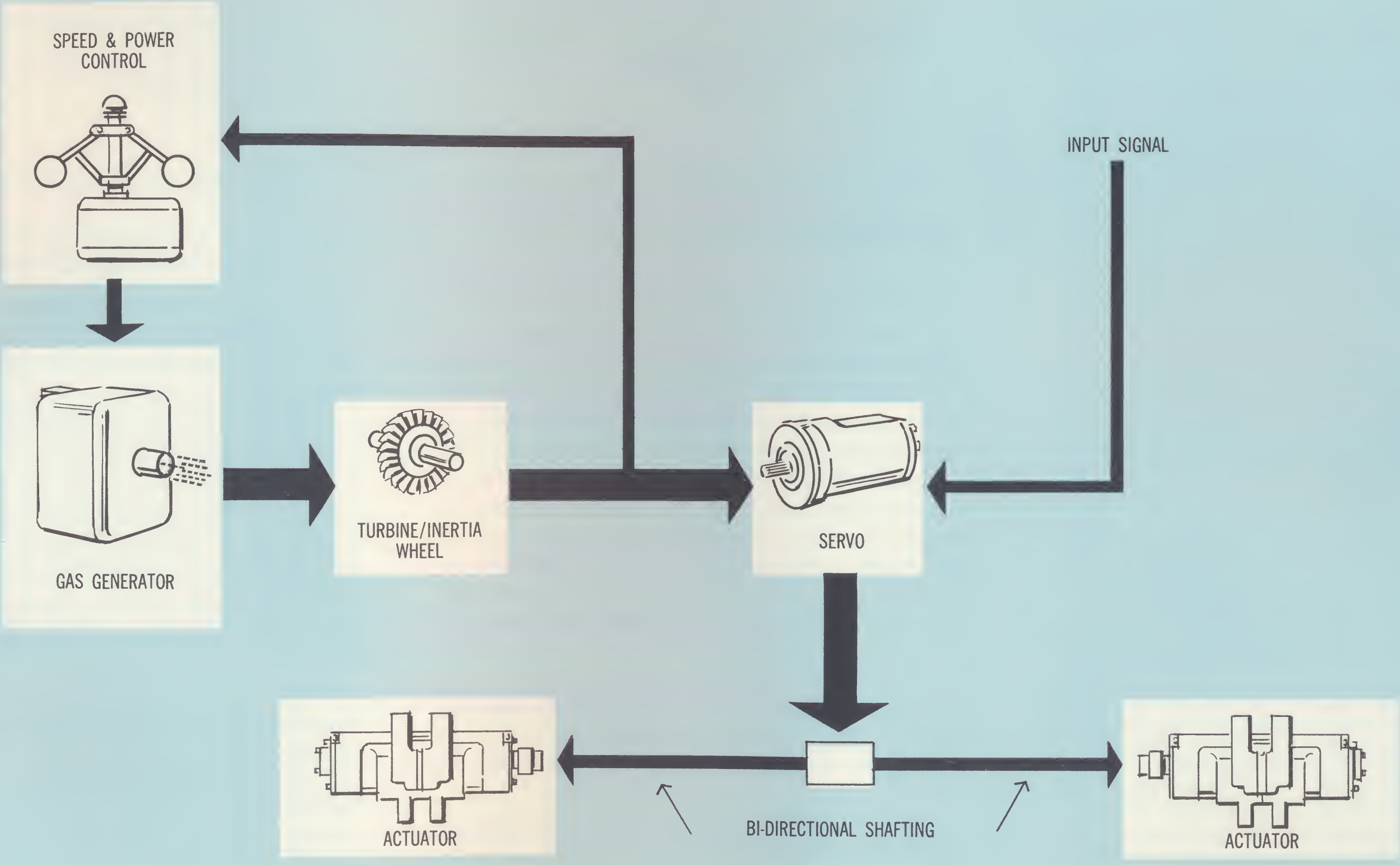


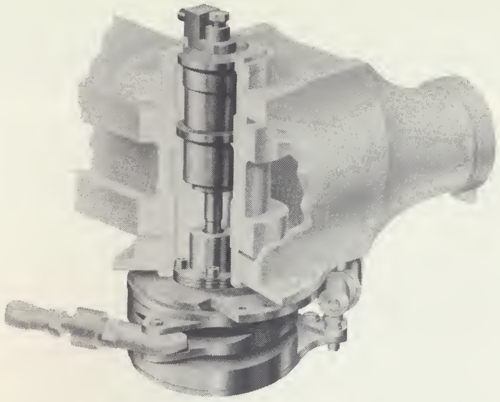
Figure 12. INTEGRATED POWER CONTROL AND ACTUATION SYSTEM

REPORT ON SOME PROJECTS UTILIZING MECHANICAL CONTROL COMPONENTS AND SYSTEMS

The feasibility of mechanical control systems has been established over a wide range of applications and sizes, from fractional horsepower systems to those requiring several hundred horsepower.

From the advanced design capability so far developed, it is becoming increasingly apparent that there are ever-widening fields of application which are ideally suited to use of the mechanical control system and components.

The following is a report on some of the projects which utilize Curtiss mechanical control components either separately or integrated into complete systems. The components described range from a small manually-operated gun actuator to primary flight control development hardware for advanced aerospace craft.



HELICOPTER BLADE-FOLD ACTUATOR

Compact Unit has High Torque-Weight Ratio

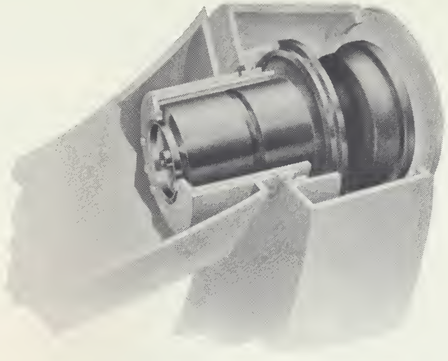
This Curtiss electromechanical actuator system, developed for the Vertol Division of the Boeing Company, provides automatic blade-folding for the U. S. Marine Corps HRB-1 helicopters. The blade-folding feature is part of the helicopters' aircraft carrier compatability.

Consisting of an electric motor and Power-Hinge actuator, the unit is mounted in the root of each of the six rotor blades. The actuation system, when electrical power is supplied, automatically folds the six blades to a position parallel to the helicopter centerline.

The Curtiss-Wright system was selected for this program because of its compact size and low weight. Other important features: high torque-to-weight ratio, aerodynamically-clean packaging.

Blade-Fold Actuator Data

Weight: Approx. 16 lbs.
Diameter: 5.75 inches
Reduction Ratio: 15,000:1 (3 stages)
Output Torque Requirements:
  Maximum Operating Torque—25,600 in-lbs.
  Maximum Static Torque—40,000 in-lbs.
Travel: 187°
Angular Rate: 18° per minute



RADAR ANTENNA DRIVES

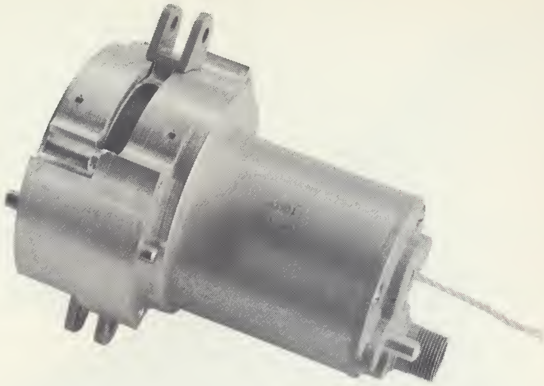
Lightweight Units Have Outstanding Stiffness Characteristics

New electromechanical antenna-drive units have been developed by the Curtiss Division for use as elevation and azimuth drives on a high-performance radar missile-tracking system. These lightweight units feature zero backlash, smooth operation, low starting torque, long life, high efficiency, and high stiffness.

An advanced multiple-spindle gear reducer, based on the Power-Hinge design, connects the antenna to the stationary structure through a number of gear teeth. This design results in a gear drive which is comparable to a spline in stiffness.

Design Basis for Radar Antenna Drive

Gear Ratio: 400:1
Maximum Output Torque: 29,000 in-lbs.
Operating Endurance: 5,000 hours
Efficiency: 75%
Cogging (Smoothness): ±0.3 oz.-in.
No-Load Starting Torque: 3 oz-in.
Torsional Rigidity (Stiffness): 56 x 10^6 in-lbs./radian
Backlash: 2 seconds of arc
Inertia: 0.1 oz-in. sec.^{2} at input
Weight (Less Motor): 25 lbs.



MISSILE THRUST VECTOR CONTROLS

Lightweight Mechanical Servo-Actuators Have Fast Pick-up Time Response and High Power-to-Weight Ratio

To meet the requirements of missile control applications, Curtiss-Wright servo-actuators are electrically signalled, reliable, storable, lightweight, and have fast dynamic response. These units combine both servo and actuator into a single package.

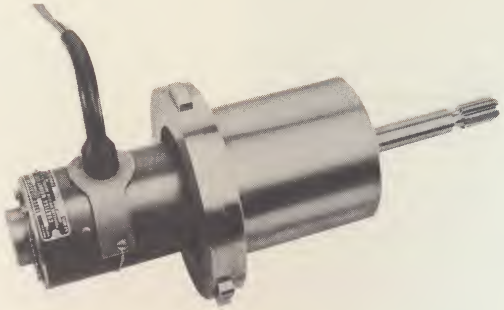
Driven by a cartridge-powered hot-gas turbine, electric motor, or other source of mechanical power, the spring-clutch servos drive the rocket nozzles through rotary actuators for rapid and accurate control of pitch, yaw and roll.

These mechanical units feature very fast pick-up time from signal start to actuator full speed—as fast as 4 milliseconds in certain designs. Load variations up to operating maximums do not change this response time. Braking action is as fast and positive as acceleration.

Laboratory tested by a major missile manufacturer, the mechanical controls met twice the endurance requirements and tracked as accurately as the hydraulic system—even when subjected to 50% higher aerodynamic disturbances.

Missile Servo-Actuator Data

Output: 2.5 hp
Weight: 5.75 lbs.
Mechanical Rotary Input:. 4200 rpm



BREECH BLOCK ACTUATOR DRIVE FOR MOBILE CANNON

Compact, Electrically-Powered Drive Withstands 750-g Recoil Impact

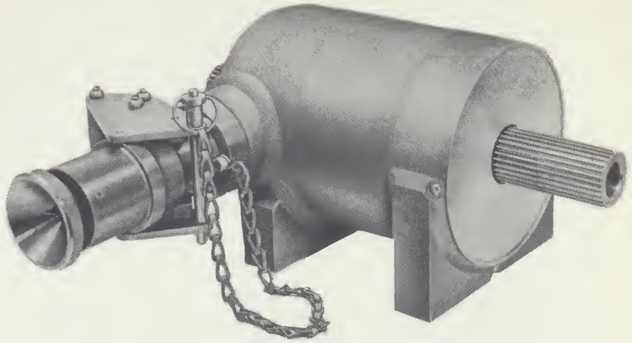
This mechanical unit, designed and built for the U. S. Army, is used to rotate and withdraw the breech of a mobile cannon.

Requirements called for an electrically-powered drive which could withstand terrific impacts, produce a 1500 in-lb output torque, and fit into a compact package. Curtiss Division engineers, to meet these requirements, developed a modified version of the Power-Hinge actuator and coupled it to a special ¼-hp motor.

Due to its advanced spindle-type gear design, this unit is capable of withstanding a 750-g recoil impact, and uses only 7 gears to produce a 255:1 reduction ratio.

Breech Block Actuator Drive Data

Weight: 14 lbs.
Length: 9 inches
Torque Amplification: 125:1
Reduction Ratio: 255:1
Output Torque Requirements:
750 inch-pounds to open breech
1500 inch-pounds maximum



GUN JACKING ACTUATOR FOR 105MM HOWITZER

Lightweight, Compact Unit is Manually-Operated

This manually operated mechanical actuator is used for positioning a mobile, lightweight 105 mm howitzer from travelling position to firing position, and vice-versa.

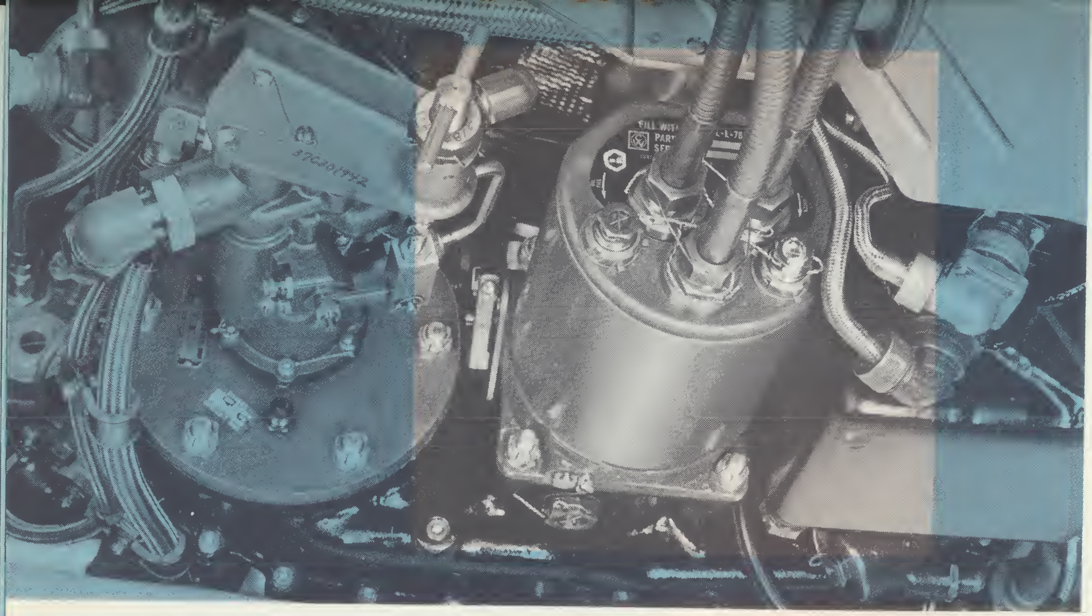
The actuator is mounted on the cross shaft which carries and supports the front wheel assembly of the howitzer. To position the cannon for firing from the travelling position, a lanyard is pulled which disengages a clutch in the actuator, dropping the howitzer off its wheels and into the firing position.

By hand cranking the actuator, the howitzer is raised back to the travelling position.

Compared to present hand-cranked units, the Curtiss-Wright mechanical actuator is lighter and more compact.

Gun Jacking Actuator Data

Weight: 36-lbs. with steel housing
29-lbs. with aluminum housing
Maximum Operating Torque: 43,500 inch-pounds
Input Torque: 350 inch-pounds
Total Reduction: 270:1
Diameter: Approx. 6 inches
Length: Approx. 8½ inches
Overall Length (Including Output Shaft Extension):
Approx. 13½ inches



VARIABLE EXHAUST NOZZLE CONTROL

Lightweight, Compact Mechanical Servos Give GE J85-5 Engines Reliable, Precise Nozzle Control

On the General Electric J85-5 engines which power Northrop T-38 supersonic trainers, mechanical spring-clutch servos are used to provide precise, smoothly-variable control of the exhaust nozzles.

From idle to 97% engine speed, the mechanical servos control nozzle area as a continuous function of throttle position. Above this, and during afterburner operation, the nozzle area is a function of both throttle position and turbine discharge temperature. Because the mechanical servos are a fully-variable control, rather than merely two-position, the jet engines deliver optimum performance and efficiency throughout the speed-altitude range.

Drawing power from engine accessory gear boxes, these mechanical servos deliver bidirectional rotation to three wire-wound flexible shafts. The shafts transmit the rotary motion to three linear actuators which are connected to the variable exhaust nozzle unison ring. The servos respond to input signals from the engine fuel control, through a mechanical linkage, to control the nozzle ring position for the desired turbine outlet temperatures. Gearing in the servo output provides synchronization of the output shaft drives and the three separate actuators.

Requirements for this jet engine application called for a compact control system which would operate reliably in the 800°F afterburner area. The Curtiss-Wright mechanical system not only solved the high temperature problem but also reduced the weight by one-third that required by an equivalent hydraulic system.

Additionally, the servos have self-contained lubrication to eliminate contamination, maintain a positioning accuracy to within 0.5% of full actuator stroke, and are less sensitive to environmental changes than a hydraulic system.

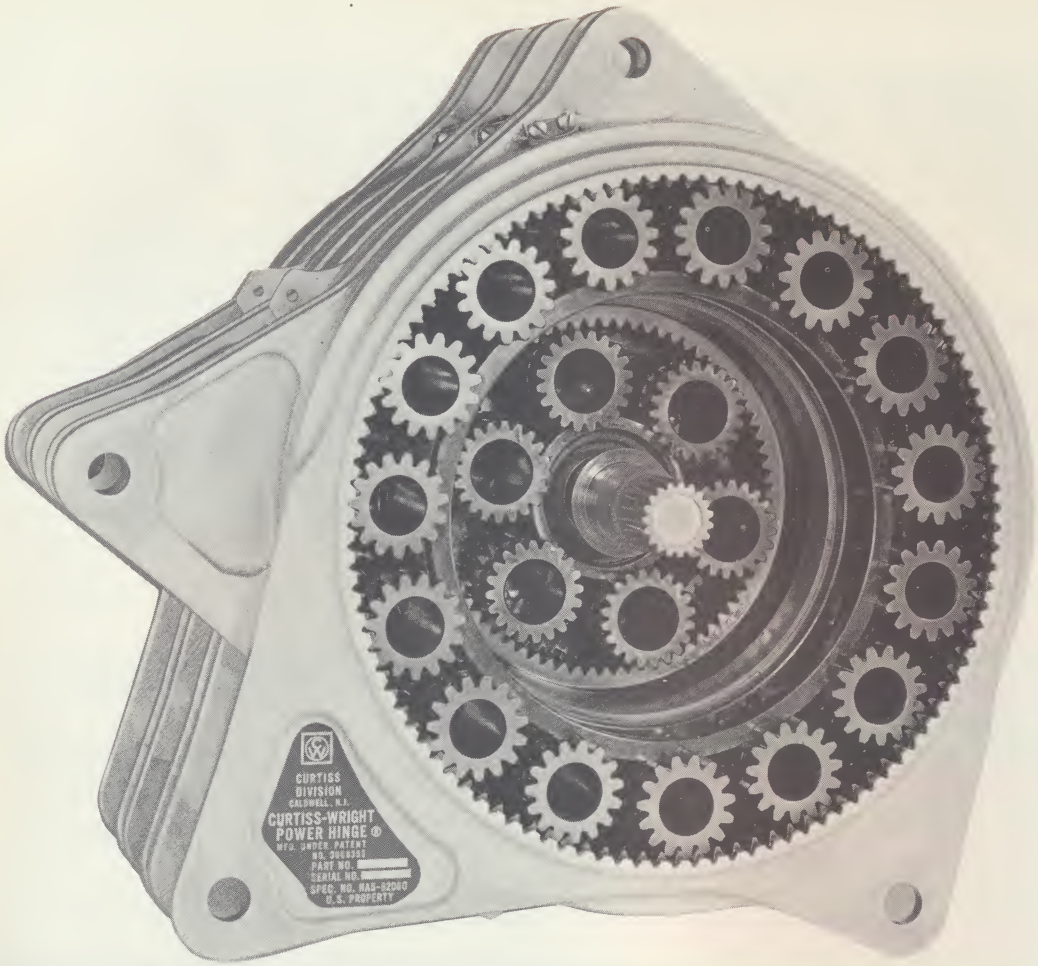
Now in production, the mechanical servos have passed all required U. S. Air Force acceptance tests and have completed over 50,000 hours of flight operation, as of August, 1962.

Mechanical Servo Data

Weight: 9.2 lbs.
Operating Temperature Range: −65°F to +350°F
Output accuracy: 1/32 inch
Output Range: 3.85 inches
Input Signal Range: 1.2 inches
Signal Force: 3 to 16 lbs.
Signal Dead Band: 0.028 inches
Lubrication: MIL 7807, Self-contained

Flexible Transmission Shaft Data

Weight: 1.5 pounds each
Length: 50 to 59 inches
Operating Temperature Range: +350°F to +800°F
Lubrication: Dry Film Lubricant



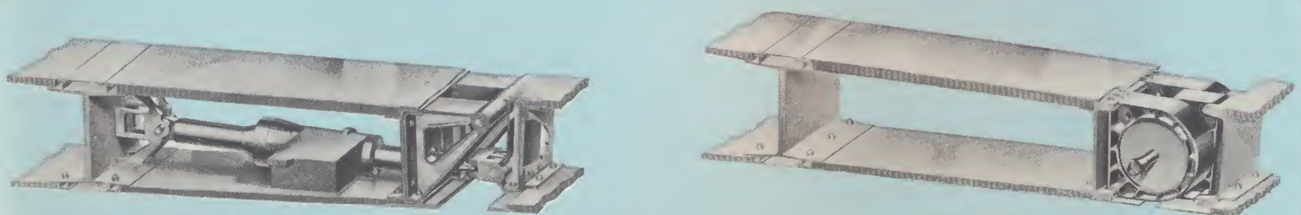
IN-FLIGHT WING FOLD ACTUATOR

Power-Hinge Actuator Solves a 4,500,000 in-lb Control Problem for North American B-70

One of the control problems posed by the B-70 supersonic bomber concerned the in-flight wing fold mechanism. Design requirements called for actuation units to hold over 4 million inch-pounds, to operate under temperature and pressure extremes met by the aircraft during supersonic flight, and to be packaged so as to stay within the aerodynamic confines of the wing.

Driven by an input shaft on the hinge line, the Power-Hinges provide high torque multiplication by using two stages of high-ratio, epicyclic gearing. This arrangement, described on page 6 of this booklet, provides the required operating torque when driven by a small hydraulic motor, and, because the Power-Hinge is designed to meet the structural stiffness requirements of the *wing itself*, it solves a severe structural problem posed by supersonic flight.

The space savings provided by the Power-Hinge is illustrated in Figure 13. This enables the vehicle to increase its range by utilizing space normally taken by fluid rams, etc., for fuel storage.



Separate Hinge and Actuator

Power-Hinge Actuator

Figure 13. SPACE SAVINGS PROVIDED BY POWER-HINGE ACTUATOR

Data

Dual stage type
Gear Reduction: 2440:1
Torque Capacity: 750,000 in-lb. (operating)
4,500,000 in-lb. (holding)
Diameter: 13 inches
Length: 10.5 inches
Backlash: Zero
Temperature: 500°F

PRIMARY FLIGHT CONTROL SYSTEM FOR HIGH-PERFORMANCE AIRCRAFT

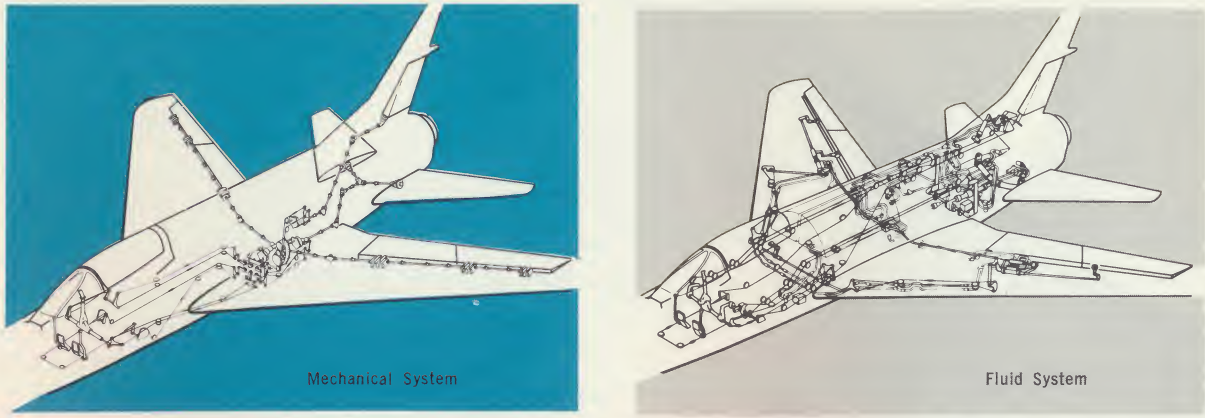


Figure 15. COMPARISON OF MECHANICAL AND CONVENTIONAL FLUID PRIMARY FLIGHT-CONTROL SYSTEMS

Mechanical System Allows Designers Freedom of Structural Arrangement and Reduces Control System Weight by as Much as 50%

In cooperation with the U. S. Air Force and North American Aviation, an all-Mechanical Aileron Control System (MACS) was designed and built to the shape of a swept-wing jet aircraft for evaluation and testing.

Development of this mechanical control system is important because of its promising advantages of weight savings, stiffness, compactness, and reliability as applied to advanced vehicles.

Figure 14 shows the mechanical system assembled in its aircraft configuration. Engine power is simulated by the variable-speed drive located at center. This continuously-rotating power is delivered to the servos and distributed as modulated power through transmission shafting to Power-Hinge actuators at the ailerons. Simulated aerodynamic loads were applied by mechanical linkages and hydraulic cylinders.

Figure 15 illustrates the basic simplicity of the mechanical system which uses rotary power from the power source to the surface actuators.

The mechanical system was also installed in the aircraft system simulator at North American Aviation. In this case, the aerodynamic loop was closed through analog computers. The mechanical system was "flown" on the simulator by several pilots with intimate knowledge of the jet fighter type aircraft simulated. Test results from this evaluation of tracking capability and response characteristics show that the mechanical control system can meet or exceed the performance of conventional hydraulic systems.

The results to date also show that the mechanical system compares favorably with a hydraulic system in areas of displacement hysteresis, threshold, break-out force, system effective-time-constant, and handling qualities.

For a capability comparision of the mechanical aileron control system with present systems, see page 4.

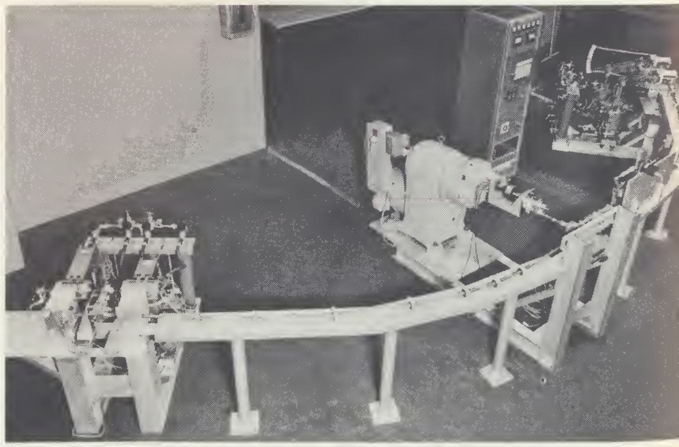


Figure 14. MECHANICAL AILERON CONTROL SYSTEM

OTHER TYPICAL APPLICATIONS UTILIZING MECHANICAL CONTROL AND ACTUATION SYSTEMS

- **Variable inlet doors**
- **Tank gun turrets**
- **Submarine control surfaces**
- **Gantry-crane platform actuators**
- **Hydrofoil retraction systems**
- **Aircraft wing flap actuators for either leading or trailing edges**
- **Wing-sweep actuators**
- **Lightweight winch mechanisms**
- **Lift-fan shutter actuators**
- **VTOL nacelle or wing-tilt actuators**
- **Jet nozzle inverter controls**
- **Helicopter control-boost actuators**
- **Submarine missile-hatch actuators**
- **Landing gear retraction**
- **Nose wheel steering**

For technical assistance in integrating a Curtiss-Wright Mechanical Control System with your specific design requirement, write or phone:

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Curtiss Division
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CApitol 6-2540
Area Code 201

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Dayton 2, Ohio
BAldwin 4-0373
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